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INFORMAL REPORT

CHARACTERISTICS OF SCATTERING LAYERS IN THE O_2 MINIMUM REGION OF THE EASTERN TROPICAL PACIFIC AND THEIR RELATION TO BIOLOGICAL AND CHEMICAL PARAMETERS

NOVEMBER 1968

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ABSTRACT

Three scattering layers exist in the minimum O_2 region of the eastern tropical Pacific. Maximum scattering within these layers was determined by decreasing echosounder gain. Regression analyses were made of various biological and chemical parameters, and correlation coefficients between these parameters and maximum scattering depths were determined. The correlation coefficients show peak nitrite concentrations to be intimately related to the shallowest migrating scattering layer. In addition, correlations between peaks of scattering in the surface layer and maximum C_{14} activity and chlorophyll a concentration suggest that these parameters may possibly be measured by high-frequency sound sources.

Trawl data suggest small bathypelagic fishes and zooplankton as causes of the shallowest migrating scattering layer and large bathypelagic fishes as the cause for the deepest layer.

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This report has been reviewed and is approved for release as an UNCLASSIFIED Informal Report.

Division Director

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INTRODUCTION

Certain marine animals are limited to stratified layers in the water column, rather than being uniformly distributed. Many of these animals undertake considerable diurnal vertical migrations which can be followed by sound ranging (Raymont, 1963; Hersey and Backus, 1962). Echosounders and filtered white noise, used to detect and study the stratified layers, have delineated general characteristics and geographic distribution of these layers (Beklemishev, 1956; Hersey and Backus, 1954; and Tchernia, 1950). Such layers occur in every major water body in the world and are commonly described as deep scattering layers (DSL).

Many attempts to identify the organisms responsible for scattering layers have produced inconclusive results. Various authors have suggested such widely diverse organisms as squid, pteropods, siphonophores, euphausiids, and bathypelagic fishes as the causative organisms. Recent research, however, has directed attention to the air bladders of certain families of bathypelagic fishes as the probable cause of the DSL phenomena recorded on echosounders (Hersey and Backus, 1954, 1962; Marshall,1951; and Andreeva, 1964). Bathypelagic fishes are believed to be intimately associated in a hunter-hunted relationship with other types of organisms which inhabit these layers. These organisms (mainly zooplankton) graze on phytoplankton which in turn are dependent on chemical nutrients and light (Aron, 1960; Beklemishev, 1956; and Raymont, 1963).

Assuming that a correlation should exist between some link in this chain and the scattering layers, research was undertaken aboard the R/V TE VEGA during April and May 1967 under the auspices of the Hopkins Marine

Station of Stanford University

METHODS

A modified Tucker trawl net designed especially for collecting macroplankton and nekton was used. Two devices were attached to the net bridle: a standard bathykymograph which recorded time versus depth and a device for presetting the time of opening and closing of the net. The net was always lowered with the mouth closed.

Scattering was recorded on two Simrad echosounders. The first, a Simrad Sonar, Model 540-4 (Simonsen Radio A.S., Oslo), was powered by a 24-volt Constavolt battery eliminator model 602A. It operated at a frequency of 30 kHz with a pulse power of 1,000 watts. This echosounder was operated on a depth-sounding mode with ranges of 0-130, 100-230, and 200-330 fathoms. A fourth range of 0-1,500 meters was rarely used owing to lack of definition of the scattering layer at this setting (fig. 2d). Most recordings were made with a pulse-length setting of one and sensitivity (gain) settings of 6 to 9. High signal to noise ratios made it impractical to record scattering layers while underway.

The second echosounder, a Simrad Echo-Sounder, Type 513-1, was powered by the ship's generators boosted from 115 to 220 volts by a Simrad transformer, Type 517-33. Pulse power was 800 watts at a frequency of 11 kHz. This instrument proved unsatisfactory for recording scattering layers owing to many artifacts that appeared on the echograms. These artifacts were believed to be caused by fluctuations in the TE VEGA power supply. Persistence of this problem throughout the cruise rendered recordings by this instrument unreliable.

Water samples were collected at each station with standard Nansen casts. The samples were analyzed for ammonia, nitrite, nitrate, phosphate, silicate, salinity, and oxygen concentrations. In addition, water was collected from the photic zone at depths of the 1, 10, 25, 50, and 100 percent light levels with a glass cylinder closed at the desired depths by a messenger. Approximately 10.5 liters were collected for C_{14} and chlorophyll measurements. Nitrate was measured by the method of Grasshoff (1964), O_2 by the Winkler method as modified by Carpenter (1965), and the remaining determinations by the methods outlined in Strickland and Parsons (1965).

RESULTS

Scattering layer analyses for the 15 stations used in this report are shown in table 1. Scattering layers were recorded before, during, and after water sample collections. In addition, echograms were taken during sunrise and evening vertical migrations. Table 1 shows the geographical position of stations, depth to top of layer, thickness of layer, and depths of maximum scattering for each layer. The survey area and the O_2 minimum region are shown in figure 1.

Figure 2 shows some representative echograms. Three recordable daytime layers were always present. The first, a shallow scattering layer, occurred at all times, varied in thickness between 62 and 173 meters, and usually increased in thickness at night when the migrating layers merged with it. Reduction of echosounder gain during the day permitted determination of the approximate depth of maximum scattering within each layer (e.g. fig. 2a). One or two such depths usually

existed in the shallow layer, but as many as three were noted. The second, and next shallowest layer, was a migrating layer. The daytime depth to the top of this layer varied between 238 and 320 meters, and its thickness varied between 22 and 95 meters. This layer showed heavier scattering on the 30-kHz echosounder than did the deepest scattering layer. Its evening migration began at the same time as that of the deepest layer, and it merged with the surface layer first. Its downward (sunrise) migration began later than that of the deepest layer and it maintained the same vertical distance between itself and the deepest layer during the migration. The deepest layer was also a migrating layer whose daytime depths varied between 325 and 440 meters. Its thickness ranged from 26 to 91 meters. This layer never showed exceptionally concentrated scattering and was barely recordable at times; however, it was always present. Migration of this layer was identical to the second layer, varying only in starting times. Migration rates ranged from 4.9 to 9.1 m/min with the rate increasing gradually from the beginning of each migration (fig. 2b) to the maximum rate.

Midday Tucker trawls at stations 659, 663, and 664 caught bathypelagic fish up to 15 cm in length at depths between 320 and 625 meters. The deepest scattering layer was within these depth limits at this time. In addition, bathypelagic fish of the same general size were caught between 270 and 385 meters at approximately 1830 local time at station 652, when the deepest layer was migrating through this depth range. Trawls towed below 650 meters showed a definite paucity of organisms. Daytime trawls made at the depths of the shallowest migrating layer contained greater concentrations of zooplankton and bathypelagic fish

much smaller than those caught in deeper trawls.

Chemical analysis of water samples showed a definite nitrite peak that varied between 200 and 325 meters. A drop in nitrate concentration associated with this peak could not be related stoichiometrically to the rise in nitrite concentration. The peak nitrite concentration ranged between 1.07 and 1.80 µg-atoms/ℓ. Figure 3 shows typical nitrite and nitrate concentrations in the area.

As previously mentioned, the approximate depth of maximum scattering within layers could be determined by decreasing the gain of the echo-sounder (figs. 2a, c, d). A least squares regression analysis of the relationship between this scattering peak and the depth of maximum nitrite concentrations is shown in figure 4. A similar analysis for the nitrite-nitrate relationship is shown in figure 5. These relationships had correlation coefficients of 0.72 and 0.65 with 95 percent confidence limits ranging from 0.4 to 0.9 and from 0.2 to 0.8, respectively. The equations for the analyses are:

$$y = 0.9418x - 19.86 \tag{1}$$

$$y = 0.5134x + 117.18 \tag{2}$$

Knowing that y equals the depth of nitrite maximum in each equation and that x equals maximum scattering depth in (1) and depth of nitrate minimum in (2), we can solve for maximum scattering depth within the second layer.

$$X\ max = \frac{0.5134\ [Z\text{-nitrate}] + 137.04}{0.9418} \tag{3}$$

Similar analyses were performed for depths of maximum scattering in the surface layer versus C_{14} productivity (fig. 6) and chlorophyll

a (fig. 7). When multiple peaks occurred, the best fit was chosen. Figures 6 and 7 show that significantly positive correlation coefficients exist between maximum scattering and the biological parameters. Other measured parameters could not be significantly related to the scattering layers.

DISCUSSION

The behavior of the migrating scattering layers in this area differs from that found in an area immediately to the north. Batzler and Westerfield (1953) report the DSL at 450 meters and a rate of migration of 2.3 m/min in the area of Guadalupe. Similar types of organisms exist in both of these areas (Wooster, 1952; Berry and Perkins, 1966), thus indicating that different chemical characteristics in the O_2 minimum region are perhaps responsible for the difference.

The characteristic immediately obvious upon inspection of the data is the relation between the pronounced nitrite peak and the daytime depths of the second layer. This peak is significantly correlated with the depth of maximum scattering in this layer. Nitrite, under these conditions, can appear in two ways. It can be reduced by organisms from nitrate or it can be oxidized from lower valence nitrogen precursors (Harvey, 1960; Vaccaro, 1965).

An associated decrease in nitrate concentration correlated with the nitrite peak suggests that nitrite is being formed from nitrate. The quantitative nitrite-nitrate difference, however, indicates that a dynamic system may be operating with the nitrite being changed at a constant rate to some other compound.

Concentrations of ammonia, although high at these depths, do not account for the nitrate loss. This suggests that either the nitrite is being changed to some intermediate compound that was not measured (e.g. N_2O_2 or N_2) or that the nitrite is somehow assimilated by organisms at these depths. Daytime vertical movement of the second layer in direct relation to nitrite-nitrate concentrations suggests that the depth of this layer is being affected by these two parameters.

Maximum scattering occurred in the surface layer at as many as three depths, suggesting that different organisms are selectively stratified within this layer. Phytoplankton probably cannot be detected with 30 kHz sound; however, these peaks may be caused by organisms not sampled but directly related to the phytoplankton. Correlation of maximum scattering with productivity and standing crop measurements indicates that these parameters are measurable with a sound source. Owing to the crude method used for determining peaks of scattering, this correlation has not been firmly established. The use of a higher-frequency sound source or perhaps filtered white noise to determine absolute peaks of scattering within the surface layer and comparison of these peaks with C_{14} and chlorophyll a maximums could lead to a rapid and easy method of determining these parameters.

SUMMARY

Three scattering layers are shown to exist in the minimum O_2 region of the eastern tropical Pacific. The surface layer, a nonmigrating scattering layer, varied in thickness between 62 and 173 meters. The top of the second layer, between 22 and 95 meters thick, had daytime depths ranging from 238 to 320 meters. The top of the third layer,

between 26 and 91 meters thick, had daytime depths ranging from 325 to 400 meters. Maximum scattering within these layers was determined by gain reduction of the echosounder. Regression analyses were made and correlation coefficients were determined between various biological and chemical parameters and depths of maximum scattering. The analyses show peak nitrite concentrations to be intimately related to the shallowest migrating scattering layer. This layer changes depth in direct relation to the nitrite peak. Maximum scattering in the surface layer was correlated with maximum C_{14} activity and chlorophyll a concentrations, suggesting that these parameters may possibly be measured by high-frequency sound sources.

Trawl catches suggest that small bathypelagic fishes and zooplankton cause the shoalest migrating layer and that large bathypelagic fishes cause the deeper layer.

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Table 1: Scattering Layer Analysis
(meters)

Date	Station Number	Lat. N.	Long. W.	Depth to Top of Layer	Thickness of Layer	Depth of Maximum Scattering
7/IV/67	652	16°22'15"	99°55'	(2) 238 (3) 338	(1) 80 (2) 36 (3) 38	(1) 45 (2) 256 (3) 357
8/IV/67	653	15 58	99°47'30"	(2) 289 (3) 369	(1) 86 (2) 22 (3) 55	(1) 54 (2) 300 (3) 409
9/IV/67	654	15 22	100 06	(2) 289 (3) 380	(1) 106 (2) 60 (3) 45	(1) 20 (2) 314 (3) 406
10/IV/67	655	14 55	100 04	(2) 320 (3) 402	(1) 132 (2) 59 (3) 27	(1) 73* (2) 354 (3) 411
11/IV/67	656	14 57	99 52	(2) 274 (3) 391	(1) 109 (2) 64 (3) 91	(1) --** (2) 312 (3) 411
12/IV/67	657	14 28	100 10	(2) 296 (3) 387	(1) 143 (2) 47 (3) 26	(1) 82* (2) 316 (3) 406
14/IV/67	658	13 50	100 50	(2) 263 (3) 411	(1) 173 (2) 95 (3) 55	(1) --** (2) 301 (3) 448
15/IV/67	659	13 26	101 36	(2) 307 (3) 417	(1) 145 (2) 50 (3) 44	(1) 91* (2) 329 (3) 435
17/IV/67	660	13 35	103 28	(2) 320 (3) 420	(1) 90 (2) 48 (3) 46	(1) 64* (2) 338 (3) 439
18/IV/67	661	13 30	103 37 30	(2) 303 (3) 391	(1) 62 (2) 40 (3) 48	(1) --** (2) 321 (3) 406

* Two or more peaks noted.
**No discernable peak.

(1) Surface layer
(2) Shallowest migrating layer
(3) Deepest migrating layer

Table 1 (con.)

Date	Station Number	Lat. N.	Long. W.	Depth to Top of Layer	Thickness of Layer	Depth of Maximum Scattering
20/IV/67	662	15°15'	104°42'30"	(2) 293 (3) 440	(1) 93 (2) 91 (3) 37	(1) 36 (2) 320 (3) 460
21/IV/67	663	16 59	103 49	(2) 267 (3) 325	(1) 88 (2) 26 (3) 27	(1) 34 (2) 281 (3) 332
24/IV/67	664	19 02	105 41	(2) 285 (3) 390	(1) 173 (2) 44 (3) 35	(1) 37 (2) 305 (3) 408
28/IV/67	665	20 58	106 24	(2) 280 (3) 305	(1) 122 (2) 50 (3) 43	(1) 20 (2) 295 (3) 420
29/IV/67	666	21 57	107 10	(2) 275 (3) 387	(1) 145 (2) 52 (3) 40	(1) 40 (2) 290 (3) 400

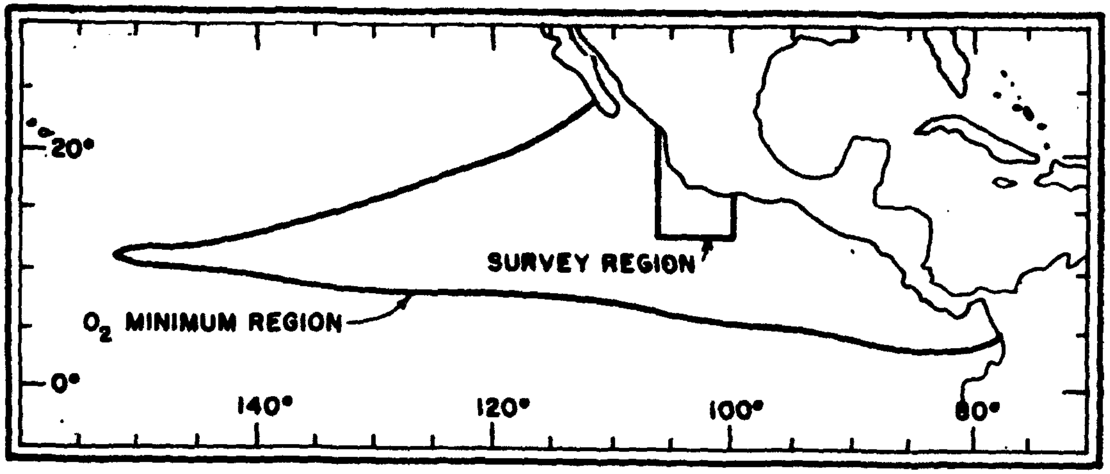

FIGURE 1 O_2 MINIMUM REGION AND AREA OF SURVEY

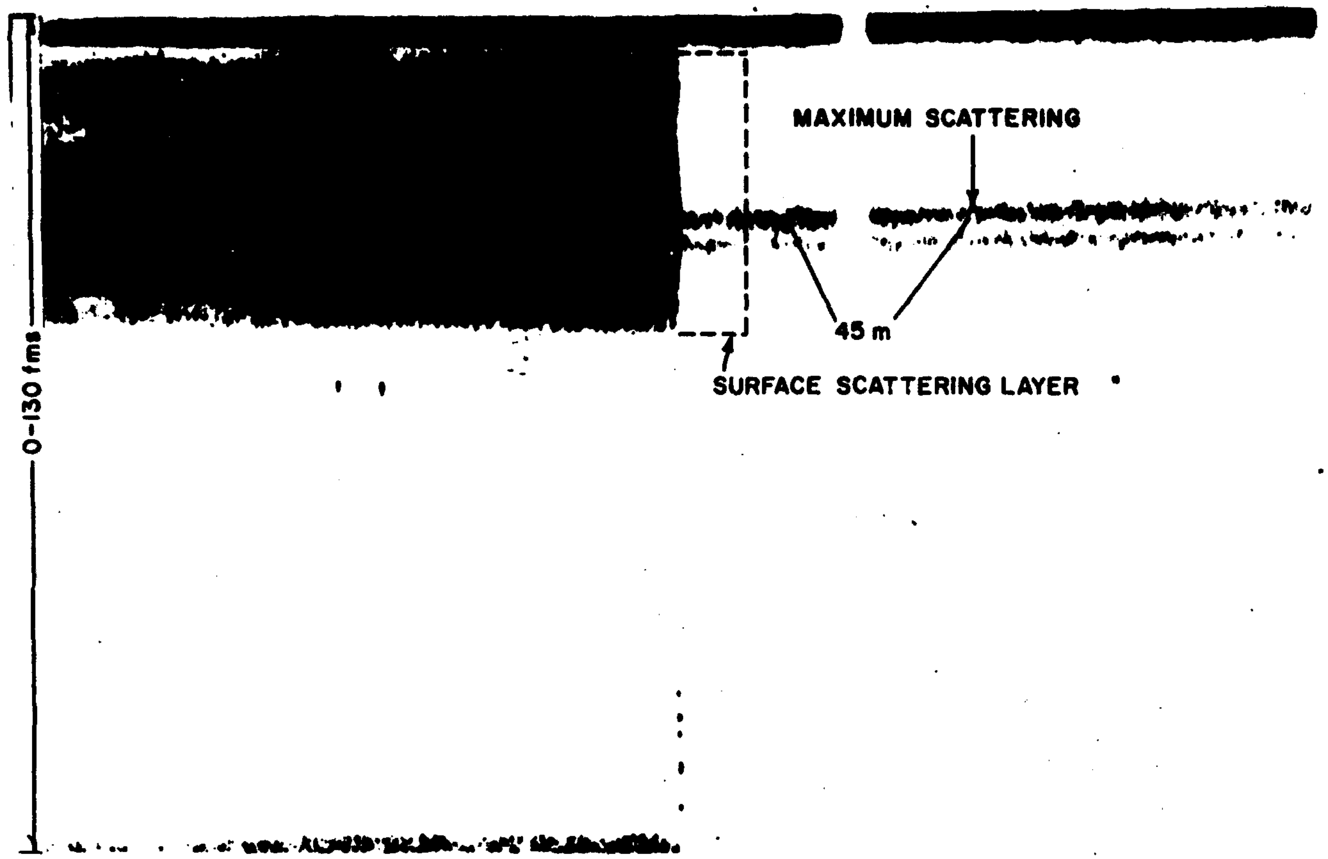

FIGURE 2a DETECTION OF MAXIMUM SCATTERING IN SURFACE LAYER BY GAIN REDUCTION

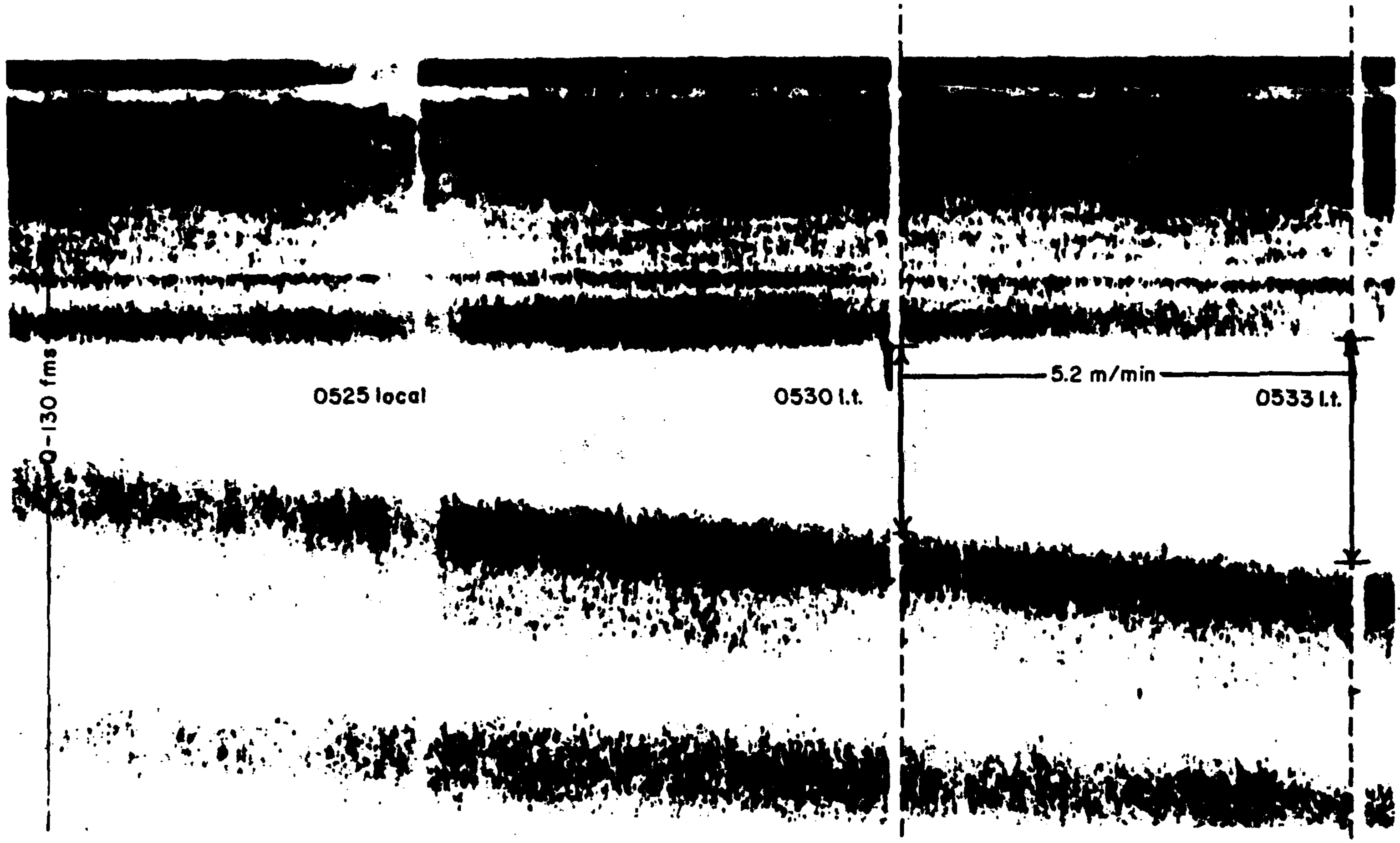

FIGURE 2b ECHOGRAM OF THE CHARACTERISTIC DOWNWARD MIGRATION OF TWO DEEP SCATTERING LAYERS, THE EQUAL SEPARATION OF THESE LAYERS, AND A MIGRATION RATE OF 5.2 M/MIN

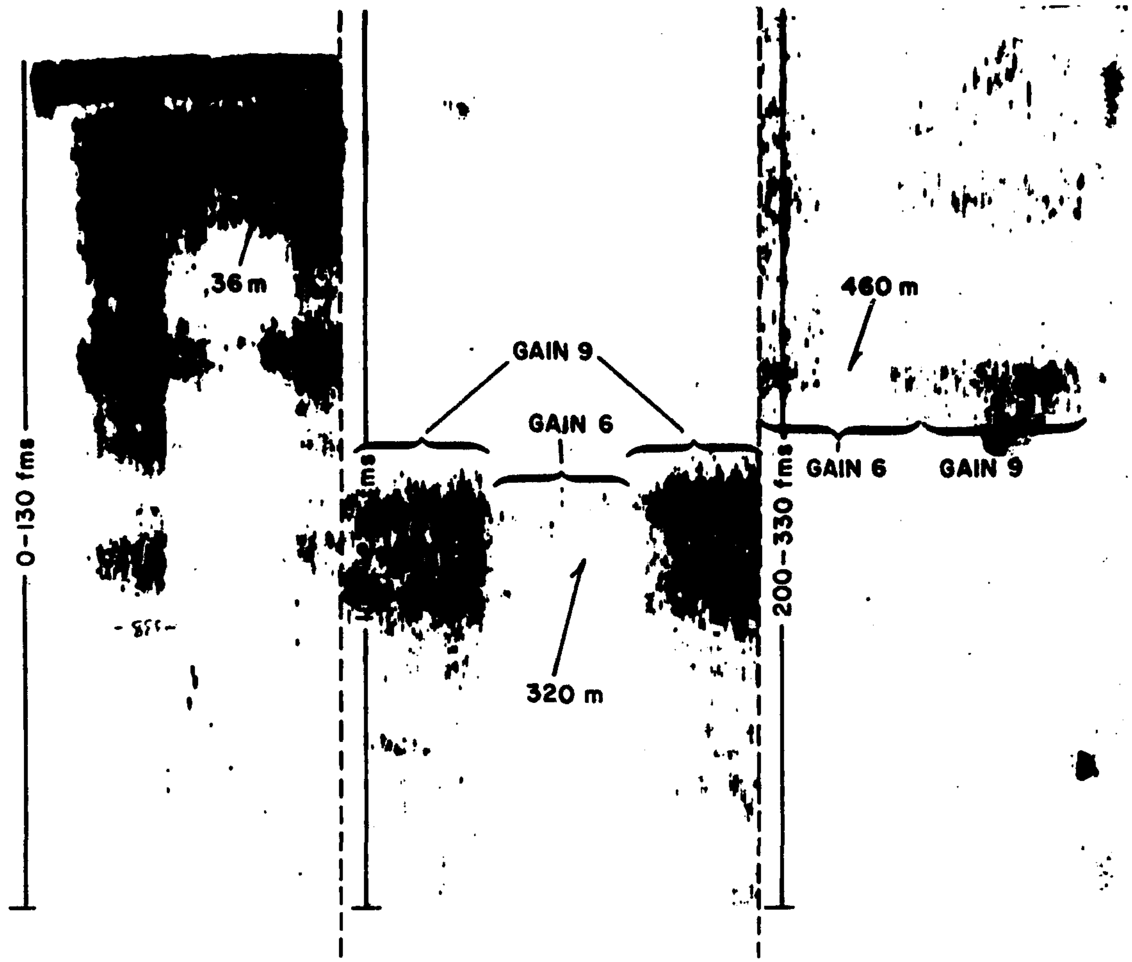

FIGURE 2c ECHOGRAM SHOWING EFFECT OF GAIN REDUCTION ON DEPTH OF MAXIMUM SCATTERING IN THREE LAYERS

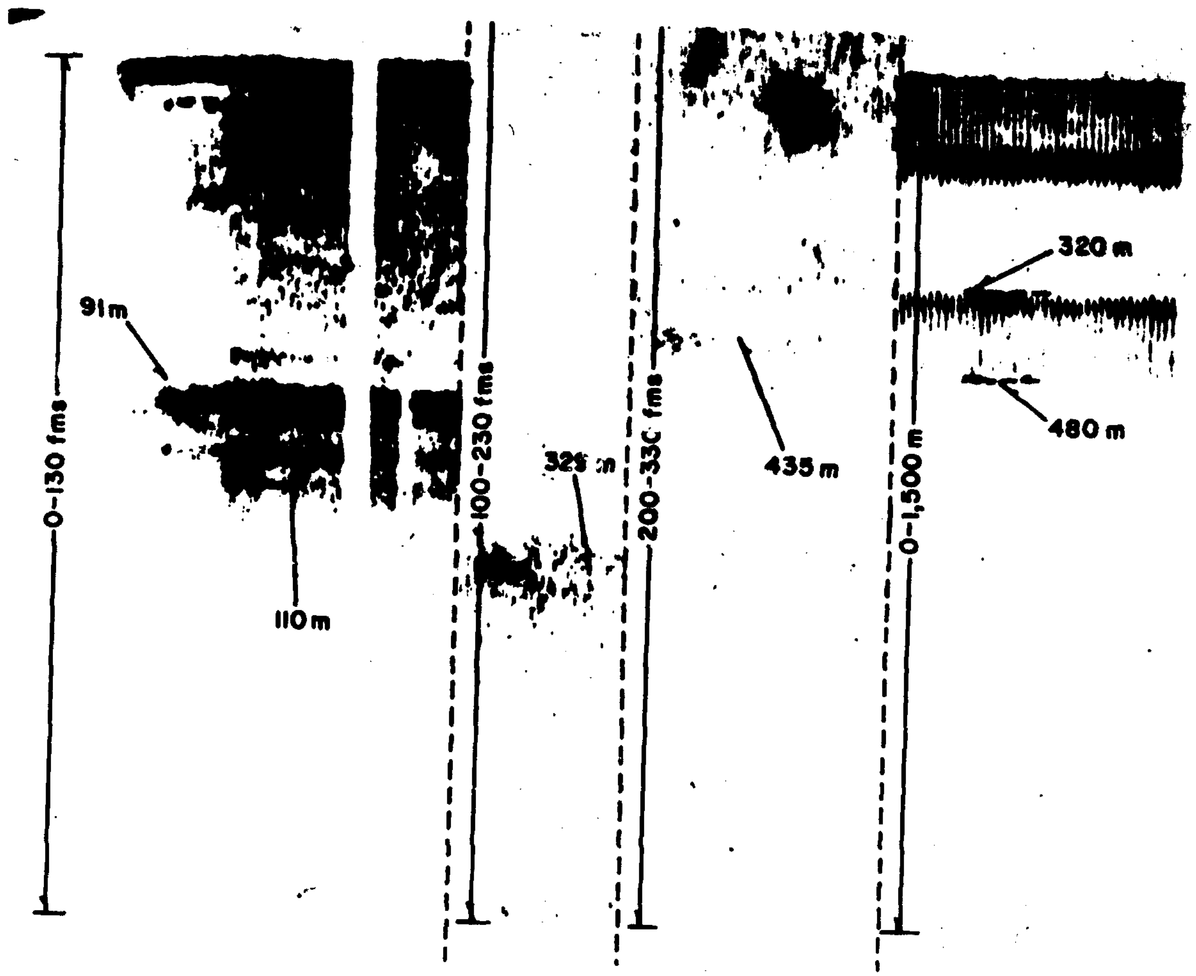

FIGURE 2d ECHOGRAM SHOWING POOR REPRESENTATION OF SCATTERING LAYERS ON 0-1,500 METER MODE

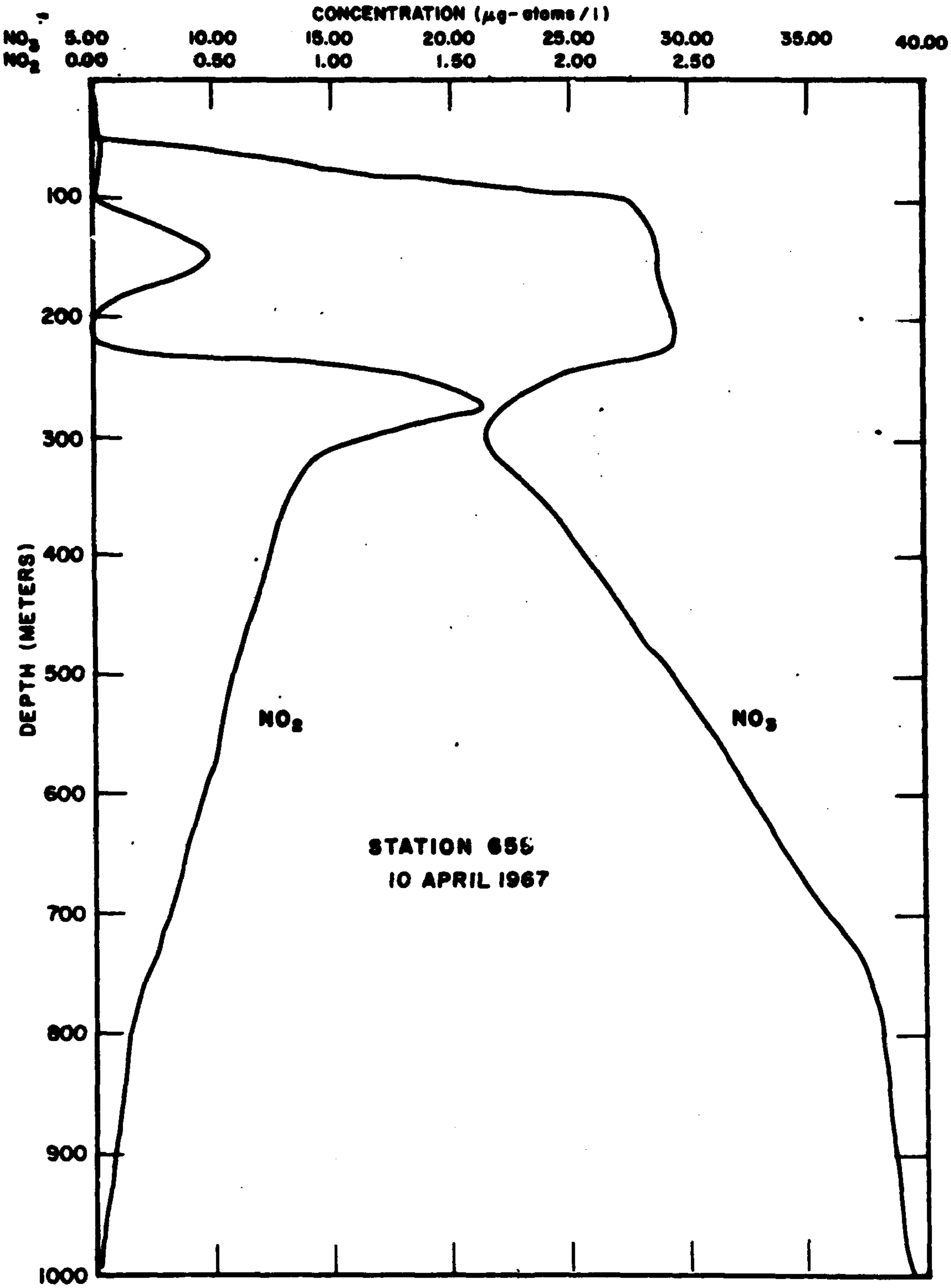

FIGURE 3 TYPICAL NITRITE-NITRATE PROFILE

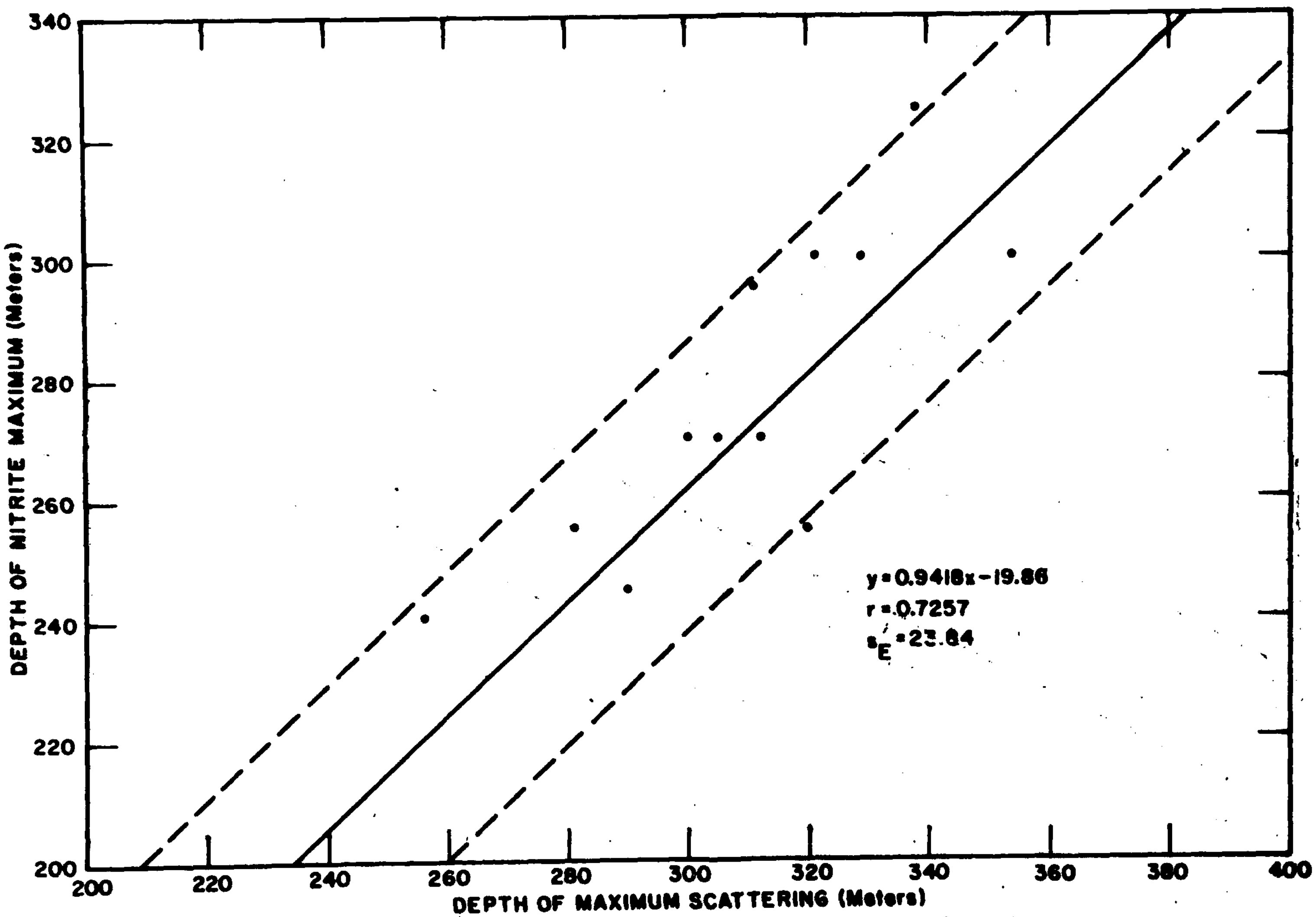

FIGURE 4 REGRESSION ANALYSIS OF NITRITE MAXIMUM VS DEPTH OF MAXIMUM SCATTERING IN SECOND LAYER

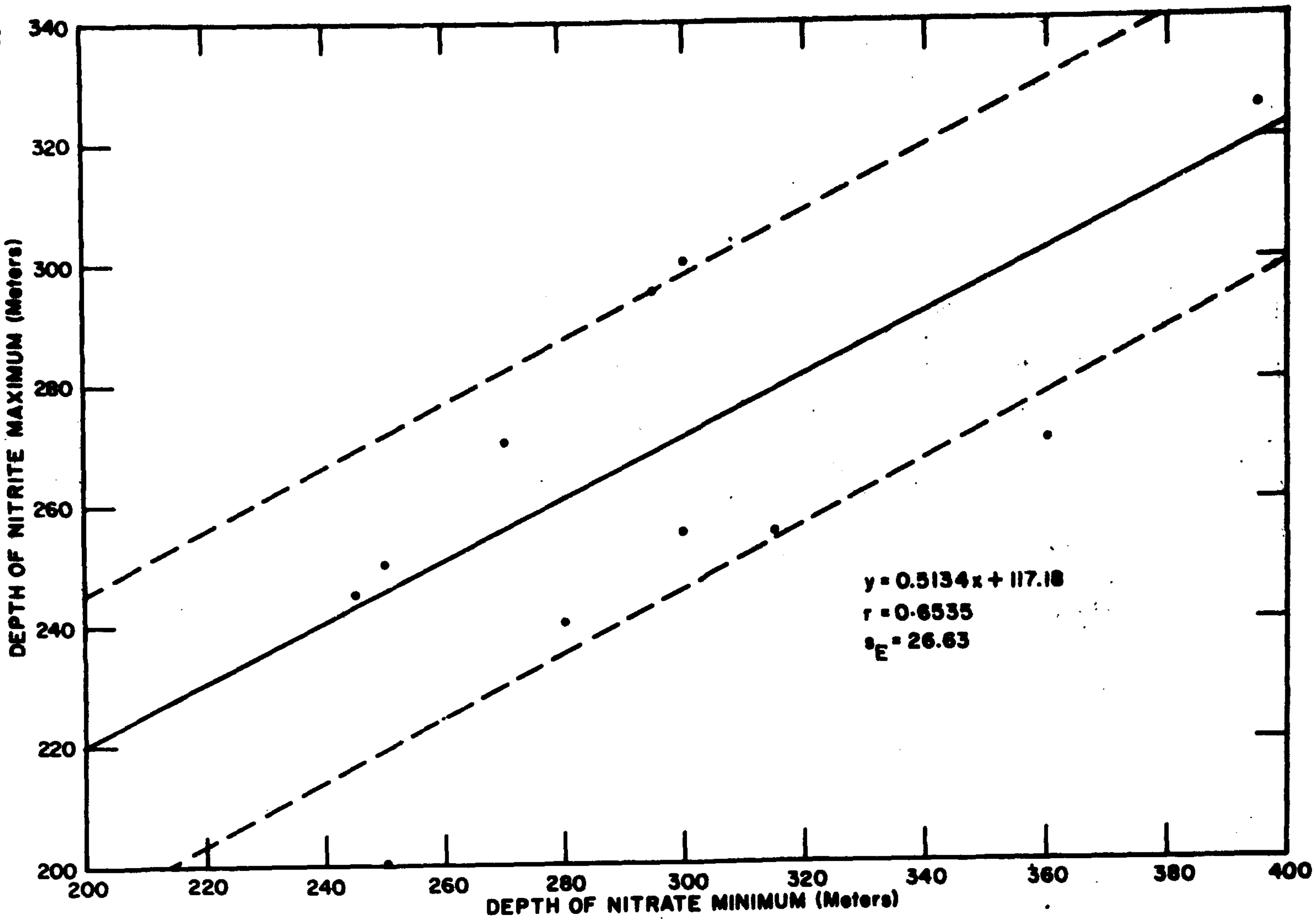

FIGURE 5 REGRESSION ANALYSIS OF NITRITE MAXIMUM VS NITRATE MINIMUM

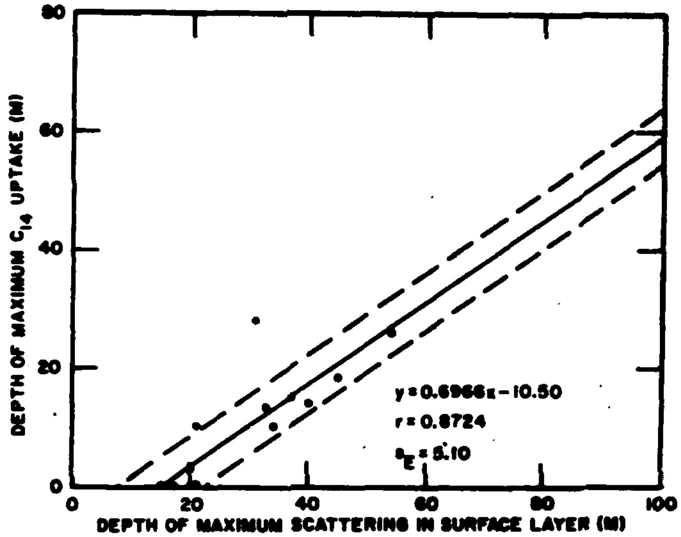

FIGURE 6 REGRESSION ANALYSIS OF MAXIMUM C_{14} UPTAKE VS DEPTH OF MAXIMUM SCATTERING IN SURFACE LAYER

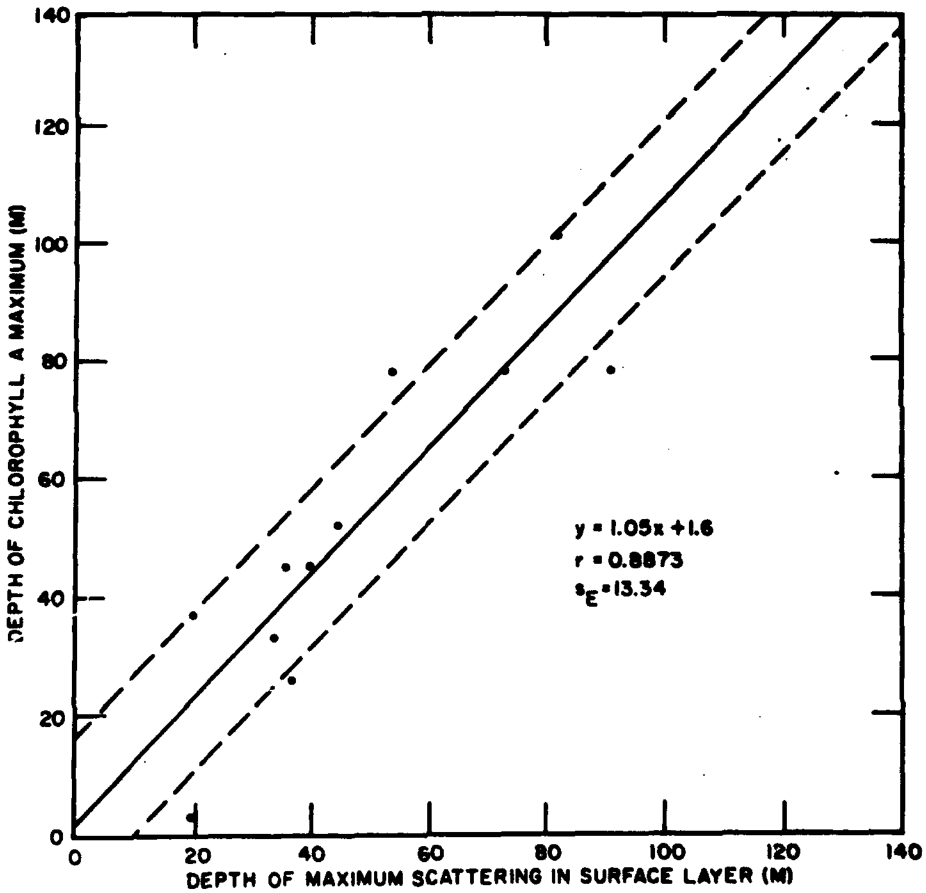

FIGURE 7 REGRESSION ANALYSIS OF CHLOROPHYLL MAXIMUM AND DEPTH OF MAXIMUM SCATTERING IN SURFACE LAYER

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Marine biology						
Nitrate						
Nitrite						
C_{14}						
0^2 minimum layer						